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Predicting the Workability of Fresh Concrete Using Simple Pull-out Test

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ABSTRACT: Workability is one of the physical parameters of concrete which affect strength and durability as well as cost of labour and appearance of the finished product. It is a vital property of concrete that must be measured correctly to ensure good quality concrete. This research study is directed towards exploring the pull-out test as an alternative test for workability of fresh concrete. The study measured the slump, compacting factor and pull-out strength for fresh concrete with water/cement ratios of 0.3, 0.4, 0.5, 0.6, 0.7 and 0.8 representing very low, medium and high workability. Result showed that a pull-out strength of 72 – 94N/mm^2 is required for concrete of very low degree of workability while pull-out strength of 62 – 65N/mm^2 is required for concrete of high degree of workability in accordance with the requirement of Road Note No. 4. The result was validated by comparing measured and calculated compacting factor and the average ratio of calculated and measured compactive factor was found to be 1.01. The calibration of calculated and measured compacting factor resulted in coefficient of determination R^2 of 0.998. These results indicate that pull-out strength is a good predictor of compacting factor and by extension workability of fresh concrete. The simple pull-out test was recommended as an alternative test to compacting factor, slump and V-B consistometer tests in measuring workability of fresh concrete.
Keywords: Fresh Concrete, Workability, Pull-out Strength

I. INTRODUCTION

Workability of fresh concrete is defined as the amount of useful internal work necessary to produce full compaction [1]. However, earlier research [2] has indicated that workability can best be described as a collective to include all essential properties of the concrete in the plastic condition. These properties comprise the following:
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i. Compatibility: The property representing the ease with which the concrete is compacted by expelling the air voids as corroborated by the research of Granville et al [1].
ii. Stability: The property of the concrete which resists segregation of its ingredients in transit or during compaction.
iii. Mobility: The property which determine the ease with which concrete can flow round the reinforcement and fill out all the angles and voids peculiar to the particular section being cast.
iv. Finishability: The property which provides a smooth surface finished by trowelling or other means.

Concrete is said to be workable when it is easily placed and compacted homogeneously i.e without bleeding or segregation. Unworkable concrete need more work or effort to be compacted in place, also honeycombs and /or pockets may also be visible in finished concrete. A good knowledge of workability is most essential for the production of a well designed concrete mix, which can be easily placed and compacted with minimum effort. The factors controlling the workability of a concrete mix are too many, prominent among them are: water content in the concrete mix, amount of cement and its properties, the overall grading, maximum size, shape, texture, porosity, mode of compaction, absorption capacity of the aggregates and temperature of the environment.

The various tests developed over the years, correlate Workability with some easily determinable physical quantity. The slump test which is used extensively in site work does not measure workability as such but is very useful in detecting variation in the uniformity of mix of a giving nominal proportions. The compacting factor test [1] was intended to measure the compactability of concrete. However, research has shown that the test is misleading for dry mixes which tend to stick in the hoppers [3]. It is found that the implied assumption that all mixes with the same compacting factor require the same amount of useful work is not always justified. The compacting factor test is mainly applicable to mixes where hand compaction may possibly be used and for site control purposes.

The Kelly ball test [4] developed in the United States of America is an alternative test to slump test. This test has the unique advantage of being applied to concrete in a wheel barrow or actually in the formwork. The test is simpler and quicker to perform than the slump test. The flow test covered by the ASTM Standard [5] does not measure workability, as concretes having the same flow may differ considerably in their workability. However, the test gives a good assessment of consistence in concrete and its proneness to segregation.

The Vebe Consistomer test developed in Sweden by Bahner [6] is basically a remoulding test. In the case of controlled concrete mixes where vibrations is invariably used, the Vebe test reproduces practical conditions and indicates a combination of both compactibility and mobility of vibrated concrete. There is no ideal test for workability. The various test results which indicates the different aspects of workability are only judiciously used in designing a concrete mix suitable for a particular job. The uses of the concrete of different degrees of workability are shown in TABLE 1.

The pull-out test measures the force required to pull out from concrete a specially shaped steel rod with an enlarged end that has been cast into that concrete. The pull-out force is related to compressive strength, the ratio of the pullout-compressive strength being 0.1 and 0.2 [7]. The vertical pullout test (VPT) [8] measured the peak interface friction angle and adhesion between soil and geosynthetic products.

The undrained shear strength of mud were evaluated using pullout test [9] and compared with standard laboratory vane shear test for undrained shear strength [10].

This study reports the use of simple pull-out test to predict the workability of fresh concrete. The procedure adopted in this research takes care of the amount of internal work necessary to give full compaction as well as other properties of fresh concrete.

II. MATERIALS AND APPARATUS

The materials used for the study were Portland cement, fine aggregates (sharp sand), coarse aggregates (granite chippings) of 12.5mm maximum size and portable water. The apparatus used were weighing balance, spring balance graduated in kilo-gram and kilo-Newton, compacting factor cylinder, slump cone and known cylindrical weight of 350g (diameter 45mm).

III. METHODOLOGY

The method consists of first burying to the bottom of the compacting factor cylinder the cylindrical weight of 350g that is tied and hung to a spring balance. The fresh concrete to be tested is poured into the cylinder and trimmed level with the top without applying any pressure. After this, the weight is pulled out of the concrete sample slowly but steadily, and the force F, needed for pulling out the weight is measured on the spring balance (the maximum force is read as it falls along the line). The same concrete specimen was tested for slump and compacting factor. Samples with water /cement ratio (w/c) of 0.3, 0.4, 0.5, 0.6, 0.7, 0.8 were tested. The pull-out force was converted to pull-out strength by dividing with the surface area of the 350g weight. The pull-out strength was computed as:

$$Pull-out\ strength\ \ P_s = \frac{Pull-out\ Force}{Surface\ Area\ of\ embeded\ Weight} \tag{1}$$

Finally, the slump and compacting factors were compared with the various pull-out strengths and provisions of Road Note 4 [11].

Table 1: Use of the Concrete of Different Degrees of Workability [11]

Degree of Workability	Slump + (mm)	Compacting Factor *		Uses for which concrete is suitable
		Small Apparatus	Large Apparatus	
Very low	0 to 25	0.78	0.80	Roads vibrated by power-operated machines. At the more workable end of this group, concrete may be compacted in certain cases with hand-operated machines.
Low	25 to 50	0.85	0.87	Roads vibrated by hand-operated machines. At the more workable end of this group, concrete may be manually compacted in roads using aggregate of rounded or irregular shape. Mass concrete foundations without vibrations or lightly reinforced sections with vibration.
Medium	50 to 100	0.92	0.94	At the least workable end of this group, manually compacted flat slabs

				using crushed aggregates. Normal reinforced concrete manually compacted and heavily reinforced sections with vibration.
High	100 to 180	0.95	0.96	For sections with congested reinforcement. Not normally suitable for vibration.

+ The slump is not definitely related to the workability or the compacting factor. The Figures given must, therefore, be regarded as providing a rough indication of the order of the slump and nothing more.

* The compacting factor figures have been obtained by means of the compacting factor test for workability described in Road Research Technical paper No. 5.

IV. RESULTS AND DISCUSSIONS

The result obtained from the pull-out, slump and compacting factor tests are as presented in TABLE 2

Table 2: Slump, Compacting Factor, Pull-out Force and Pull-out Strength

W/C Ratio	Slump (mm)	Compacting Factor	Pull-out Force (N)	Pull-out Strength (N/mm^2)
0.3	0	0.75	150	94.3
0.4	3	0.80	140	88.0
0.5	7	0.83	118	74.2
0.6	12	0.85	115	72.3
0.7	55	0.87	108	68.0
0.8	78	0.90	106	66.6

4.1 Development of Predictive Equations for Workability

The results of compactive factor and pull-out strength presented in TABLE 2 were used to develop regression equation relating compacting factor and pull-out strength. The regression equation was based on nonlinear general equations (2) using SPSS [12]. The relationship between pull-out strength and compacting factor was best fitted using equation (2) and is shown in Fig. 1.

$$y = ax^{b} \qquad (2)$$

Where,
y = Compacting factor
x = Pull-out strength (N/mm^2)
a and b are constants

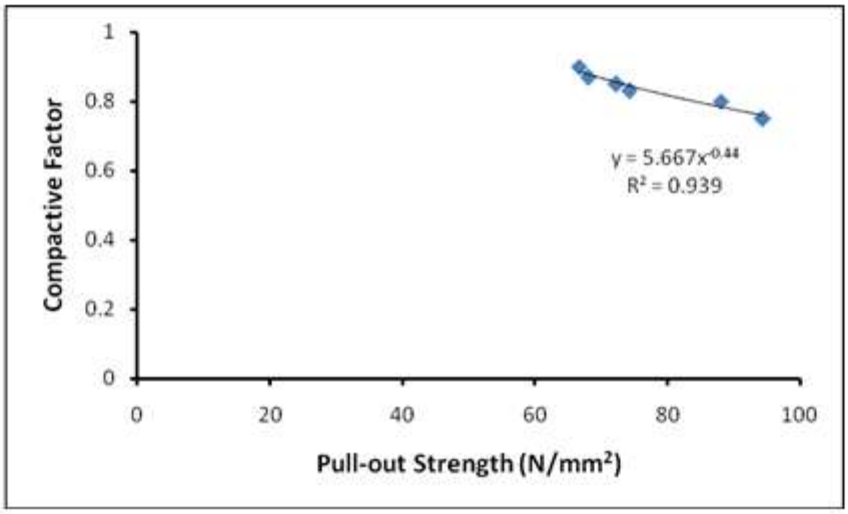

Figure 1: Relationship between Compacting Factor and Pull-out Strength

From Fig. 1, the predictive equation relating pull-out strength and compacting factor is as shown in the equations (3) as follows:

$$C = 5.667P_s^{-0.44} \qquad R^2 = 0.939 \qquad (3)$$

Where,
C = Compacting factor
P_s = Pull-out strength (N/mm^2)

4.2Analysis of Result

The analysis of the result was in two aspects. Firstly, by merging TABLE 1 with TABLE 2 to obtain TABLE 3 and secondly, by comparison and calibration of measured and calculated compacting factor results.

Table 3: Degree of workability, Pull-out strength and Uses

Degree of Workability	Pull-out Strength (N/mm^2)	Uses for which Concrete is Suitable
Very Low	72 – 94	Roads vibrated by power-operated machines. At the more workable end of this group, concrete may be compacted in certain cases with hand-operated machines.
Low	68 – 71	Roads vibrated by hand-operated machines. At the more workable end of this group, concrete may be manually compacted in roads using aggregate of rounded or irregular shape. Mass concrete foundations without vibration of highly reinforced sections with vibration.
Medium	66 – 67	At the least workable end of this group, manually compacted flat slabs using crushed aggregates. Normal reinforced concrete manually compacted and heavily reinforced sections with vibration.
High	62 - 65	For sections with congested reinforcement. Not normally suitable for vibration.

In accordance with the provisions of Road Note 4 [11], TABLE 3 shows that a pull-out strength of 72 – 94N/mm^2 would be required for concrete with very low degree of workability while 62 – 65N/mm^2 would be required by concrete of high degree of workability. The intermediate values of low and medium workability would require 68 – 71N/mm^2 and 66 – 67N/mm^2 respectively. TABLE 3 also shows the degree of workability, pull-out strength required and uses in accordance with Road Note 4 [11]

The result of measured and calculated compactive factor of fresh concrete is presented in TABLE 4. The average ratio of calculated and measured compactive factor was 1.01. The calculated and measured compactive factor were calibrated and compared using linear regression analysis as shown in Fig. 2. The calibration of calculated and measured compacting factor resulted in coefficient of determination, R^2 of 0.998. This result indicates that pull-out strength is a good predictor of compacting factor and by extension workability of fresh concrete.

Table 4: Ratio of Compacting Factor and Pull-out Strength

W/C Ratio	**Pull-out Strength (N/mm^2)**	**Compacting Factor**		
		Calculated	**Measured**	**Ratio**
0.3	94.3	0.76	0.75	1.01
0.4	88.0	0.79	0.80	0.99
0.5	74.2	0.85	0.83	1.02
0.6	72.3	0.86	0.85	1.01
0.7	68.0	0.88	0.87	1.01
0.8	66.6	0.89	0.90	0.99
Average Ratio				**1.01**

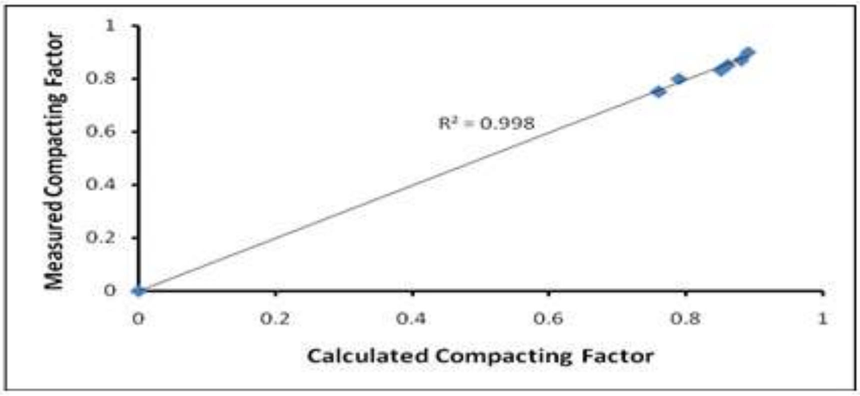

Figure 2: Calibration of calculated and measured compacting Factor

4.3 Advantages of Pull-Out Test

i. The pull-out test provides for easy means for the determination of the workability of a concrete mix.
ii. The speed of performing the test is a major advantage. Testing can be done in a matter of minutes and thus saves time.
iii. The test could go a long way to promoting insitu testing which is a very vital aspect of quality control.
iv. The pull-out equipment is simple to assemble and use. The principal parts, the spring balance and metal weights are commercially available, other peripheral parts can be manufactured locally. It also uses the compacting factor apparatus.
v. The equipment is safe for use due to its simple nature.

V. CONCLUSION

From the result of the study, the following conclusions are hereby made

1. The pull-out test has proved to be good, fast and easy test for predicting workability of fresh concrete.
2. Pull-out strength of 72 – 94N/mm^2 and 62 – 65N/mme^2 are required for concrete of very low and high workability respectively.
3. The relationship between pull-out strength and workability as presented in TABLE 3 is recommended for use
4. The simple pull-out test for fresh concrete is recommended as an alternative test to compacting factor, slump and V-B consistometer test in measuring workability
5. The pull-out test is recommended for insitu-testing for the workability of fresh concrete.
6. It is recommended that Agencies develop and standardize their equivalent pull-out strength corresponding to the slumps and compacting factors.

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